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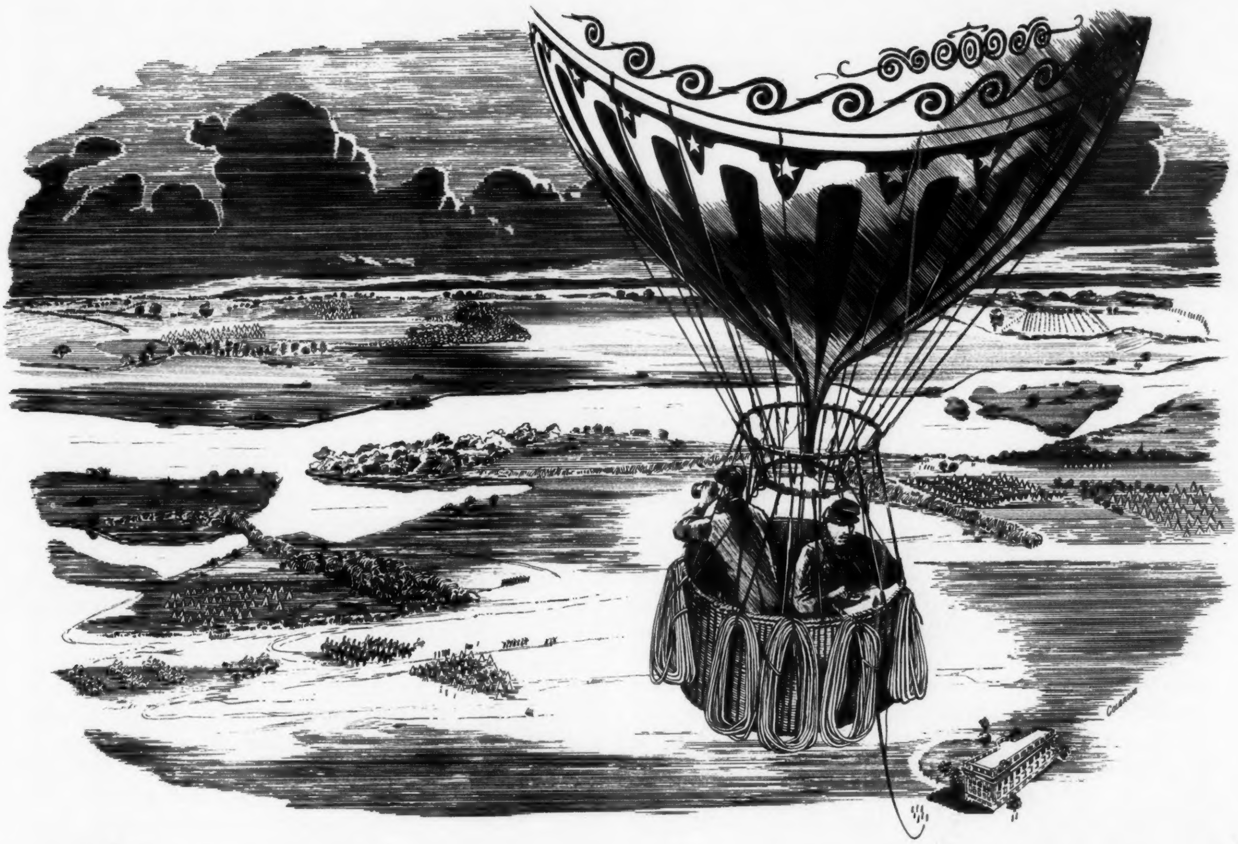


The Problem of COMBAT SURVEILLANCE

by HERBERT A. NYE, Ph.D.

THE last days of July, 1861, found the North on the brink of disaster. When McDowell withdrew from Manassas, he left a strong, threatening Confederate force in the area. There was good reason to believe this force would attempt to occupy the Capitol. Washington's defenses were marginal at best. The northern side of the city was virtually unprotected. Should the Confederate forces move up the Potomac, effect a crossing into Maryland, and attack by surprise from the north, Washington would be lost. Movement of the Confederate forces either directly toward Washington or up the Potomac would indicate an attack, and knowledge of any such movement was vital to the defense of the nation's capital. It was during these dark days following the first Battle of Bull Run that Thaddeus Sobieski C. Lowe arrived in Washington with his balloon.

Lowe was received in the White House, where arrangements were made to finance a demonstration. He filled his balloon from the city gas main, hired a telegraph operator, and made an ascent. From a position 500 feet above Washington, Lowe telegraphed Lincoln, reporting that his view commanded a 50-mile circle.

The following day Lowe made an ascent from the White House grounds. Then, at the request of General McDowell, he made a surveillance ascent on the Virginia side of the Potomac, which resulted in a good map of the Confederate camp. The problem of a surprise attack on the Capitol was eliminated and Lowe was hired as a military aeronaut. Throughout the fall

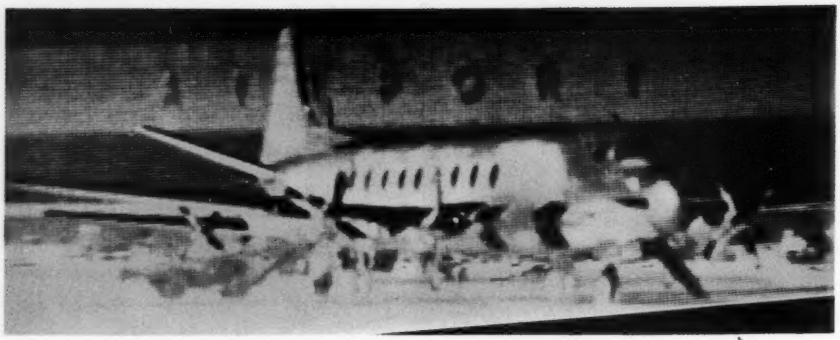


Image produced by scanning with a detector sensitive to infra-red energy radiated by the subject in total darkness. (Photograph courtesy of Barnes Engineering Company.)

and winter, balloon ascents along the Potomac kept the Confederate forces under surveillance, while McClellan directed the bolstering of Washington's defenses. The following spring, balloon observers reported the withdrawal of rebel forces from the Manassas area.

Current Emphasis on Problem

This use of surveillance balloons in 1861 provided a new solution to an old, old problem. The need to know the location of the enemy, his disposition and strength, and his movements is as old as war itself. Today, however, largely because of the introduction of missiles and nuclear warheads into the arsenal and because of the innovations in tactics which the new weapons permit or require, the development of an adequate combat surveillance capability is one of the most important problems facing the U.S. Army. Commanders at each echelon must be provided with data on the battlefield situation in sufficient detail, of sufficient accuracy, and with sufficient rapidity to form the basis for effective tactical plans and decisions. In order to make effective use of weapons available to the different commands, each level of command must be provided with a surveillance capability commensurate in range with the range of its weapons.

The importance of the combat surveillance problem is particularly evident when considering the employment of nuclear weapons in military operations. In such operations timing will be critically important. Army units will attempt to move rapidly on the ground and will possess some integral capabilities for air transport. Targets will become more fleeting. Camouflage and movement at night and in bad weather (to circumvent air attack) will become more common. The timely location of target coordinates under these circumstances, and, conversely, the need for a shifting defensive posture, will require more dynamic actions and decisions, and consequently more rapid, complete and precise intelligence. Also, the enemy may possess more precombat information, making a capability for rapidly obtaining information during combat more important.

The need for an improved combat surveillance capability applies equally to the limited war with conventional weapons. Our Army is committed to a dual capability; this must be and is reflected in currently evolving tactics and organization. Because of the nature of the threat, the Army must possess strategic mobility, as well as a tactical mobility, to permit rapid intra-theater movement of troops and supplies. The classic roles of tactical aviation for close support and reconnaissance will pass, at least in part, to surface-launched missiles and to surveillance systems organic to the ground forces.

Surveillance Problems Studied

For some years the Cornell Aeronautical Laboratory has examined the problems of reconnaissance and surveillance. This interest has been a natural outgrowth of the Laboratory's role in the development of Lacrosse, the missile with the "built-in" target-location capability, and of numerous other CAL studies and research and development activities concerned with improving our nation's tactical warfare capability. Since December, 1957, CAL has operated the Combat Surveillance Project, sharing quarters in Arlington, Virginia with the U.S. Army Combat Surveillance Agency. This Project makes technical evaluations of candidate equipments for combat surveillance, assesses the adequacy of existing and proposed equipment complexes in the light of Army requirements, and makes recommendations to the Combat Surveillance Agency for new developments and supporting research programs.

Equally important contributions are being made to the field of surveillance at the Laboratory proper in Buffalo. Studies being performed for the U.S. Army Signal Corps include a comprehensive investigation of technological requirements for surveillance drones and the synthesis of advanced target-location systems concepts. In other projects specific reconnaissance techniques are being studied which contribute to the advancement of relevant technologies.

Surveillance Functions Required

One of the important functions of combat surveillance considered in CAL's work is the timely and accurate determination of the coordinates of potential targets for available weapons, including both conventional artillery and missiles. Meeting the precise requirements of target location presents some of the most difficult technological problems of combat surveillance.

Another important surveillance function is that of intrusion detection. Current concepts of the battlefield of the future envision widely dispersed forces. Maintaining the integrity of such forces will be difficult. Combat surveillance must provide protection against enemy infiltration.

Another function completely new to warfare is that of nuclear surveillance. All nuclear detonations, both hostile and friendly, must be detected and assessed. This information, together with meteorological data, will aid in the protection of friendly forces as well as

in damage assessment of both friendly and hostile deliveries.

All these surveillance functions will be rendered more difficult by the high degree of mobility the enemy may be expected to possess. Profitable targets may remain profitable only briefly. The enemy situation as seen or sensed at a given time may change completely in minutes. Information which is to provide the basis of appropriate tactical decisions must be presented to the commander with an absolute minimum of delay. Appropriate processing and dissemination of the vast quantity of data accumulated by surveillance sensors thus is vital to effective combat surveillance. Surveillance information must be presented to the particular commander who requires it, at the time he requires it, and it must be presented in a form meaningful to him. The information-processing problem would be challenging even with only the existing information-gathering capability. The data-gathering capability currently under development makes the problem truly difficult. The information-processing complex must exploit the capabilities of both men and machines. It must be matched at one end to the data-gathering capability of surveillance and other intelligence sources, and at the other end to the basic information requirements for command decision.

Tools for Combat Surveillance

The list of candidate sensors for combat surveillance is long and includes optical aids, photography, television, passive and active infrared, radar, flash- and sound-ranging sets, and seismic and acoustic devices. Sensors alone, of course, do not provide an information collection capability. While examples of each of these sensors designed for use on the ground exist, airborne surveillance systems are necessary to provide depth of coverage. Even in forward battle areas airborne systems are needed to overcome line-of-sight limitations, to permit wider coverage and more flexible operations, and most particularly to enhance the target location capability.

The advantages of aerial platforms for surveillance purposes have long been recognized. Surveillance balloons were used not only in our Civil War, but in the Franco-Prussian War and in World War I as well. Manned kites used in World War I permitted observation of the enemy through powerful glasses from heights up to 2000 feet. General David Henderson* emphasized the need for aerial surveillance in this way: "The inventions of modern science, as adapted to warfare, have hitherto tended to loosen the control of a commander over his troops in battle; the perfection of long-range weapons has caused such dispersal of troops that even with improved methods of communication, it has been impossible for commanders to keep themselves thoroughly informed of the position and condition of their forces in action. The aeroplane has altered all this; there is now no reason why a chief commander should not have the same knowledge of the progress of an action, even if his battle line be 50 miles long, as Wellington had, and used so decisively at Salamanca." True as these words were when they were written, prior to World War I, what new meaning they have today!

The USD-2 drone, one of several pilotless surveillance vehicles now under development.

While there is a role for manned aircraft surveillance systems, unmanned systems must receive special emphasis. For close-in surveillance, such systems must be designed for simplicity and for the minimum logistics and maintenance necessary for equipments to be used at low levels of command, otherwise the responsiveness to the surveillance needs of their command levels of airborne surveillance organic to the Army will be illusory. Unmanned systems for surveillance deep in enemy territory are also needed when intensive hostile air defense precludes manned aircraft operations; drones used in this application must have performance compatible with survival.

Progress in Sensor Technologies

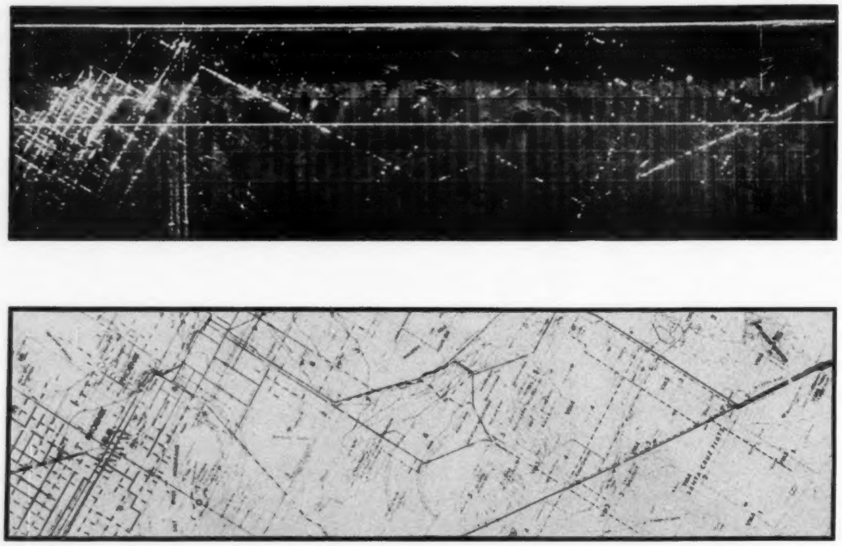
Substantial progress has been made in the past few years in all areas of sensor technology. Especially worthy of mention are airborne radar, photography, infrared and low-light-level television. Promising methods of nuclear surveillance have been developed. Both manned and unmanned airborne surveillance systems including a variety of sensors have been developed and tested. Mr. Lowe's balloons, of course, have been replaced by airborne platforms beyond his dreams, just as his field glasses have been replaced by more versatile sensors. Similarly, compass bearings and the visual estimate of range have given way to other techniques for locating objects of interest, and the air-ground communication link is no longer a combination of telegraph, signal flags and the process of attaching messages to rings and sliding them down the balloon anchor ropes.

As a specific example of recent technological advance, the Project MICHIGAN high-resolution radar is an interesting and significant development. Airborne radars, while offering the distinct advantage of increased range to horizon, have in the past provided relatively poor resolution because of the limited physical size possible in airborne antennas. The Michigan

*Brigadier-General David Henderson, "The Art of Reconnaisance." John Murray, London, 1914, p. 181.

radar makes a small antenna perform like the exceedingly long antenna necessary for high resolution, by exploiting the aircraft's forward movement and by using a special data processing technique in which returns are stored and processed to obtain the resolved target image. This system in effect also provides a resolution independent of range.

Another development with potential military applications is that of an image orthicon which operates at extremely low light levels. This device, by integrating the light reflected from its subject over a brief period of time, can provide a clear televised image of a scene in almost total darkness.



Above: radar map of moving traffic in Phoenix, Arizona, made by an airborne radar capable of discriminating between moving and stationary targets. Below: corresponding street map of the same area.

Need for Systems Analysis

These examples are illustrative of the numerous advances which have been made in recent years in technologies applicable or potentially applicable to surveillance. What, then, are the major problems today confronting CAL and others attempting to provide our Army with an improved surveillance capability? Intensive research and development can undoubtedly yield sensors of greater sensitivity and improved resolution, navigation systems of greater precision and accuracy, airborne surveillance vehicles of higher performance or lower cost.

Of equal importance to these technological problems are those of "systems analysis." The problem of target acquisition can serve as a first example of a serious problem for systems analysis. Target acquisition involves more than the determination of the coordinates of targets with an accuracy sufficient for effective delivery of appropriate warheads. Target acquisition implies detection and identification as well as target location. Conceivably there will be instances in a future war in which this will be a simple matter of one, two, three. Such an instance can be expected to be somewhat of a rarity, however; the more general situation being one in which detection and identification each result from a complex but rapid analysis involving indicators and signatures from more than one source or sensor. The process by which targets for the new missiles will be found must be better understood before it can be known with certainty that the surveillance and target location systems currently under development will provide a sufficient capability.

A second problem in systems analysis is that of providing proper guidance to a long-range program for combat surveillance. The military strength of our nation depends upon how intelligently we apply our technology. Since not all of the ideas that engineers and scientists dream up can be carried to completion, a process for the selection of new weapon systems to be developed and of the exploratory research to be undertaken must be established. Limited funds and technical man-power require that the combat surveillance program be properly focused.

This problem, of course, is not unique to combat surveillance. In many areas, however, such as those of continental air defense or strategic retaliation, the mission to be accomplished can be stated much more readily in terms which permit a quantitative comparison of alternate technical approaches to the problem. The greater difficulty in doing this for combat surveillance does not decrease the need to find a way to perform comparative evaluations of proposed alternate systems prior to the launching of expensive development programs, and to establish, on the basis of such evaluations, criteria to be used in guiding long-range research. This evaluation problem is far from solved, but, fortunately, it is now beginning to be recognized and understood, and some progress is being made.

The increased pace of technological development is reflected in the rapid evolution of new military tactics. It is important that our surveillance capability keep pace with weapon potentials and with the tactics reflecting these weapon potentials if the adequacy of combat surveillance is to be maintained. The many technologies which can contribute to combat surveillance are well advanced. The current development program is designed to exploit this advanced state of the art as fully as is now possible. In anticipation of operational experience to be gained with the products of this development program and with the study of effects of combat surveillance techniques through war games and other types of analysis, the Army can look forward with confidence to a combat surveillance capability adequate to its needs in this atomic age.

LIGHT SOURCE *for High-Speed Photography*

by MERLE R. WILSON and RICHARD J. HIEMENZ

Ever since the Messrs. Wright broke the ice, the aeronautical fraternity has paid heed to Milton's advice: "To thy speed add wings." During the past fifty-odd years the cry: "More speed! More speed!" has become a tumult. Corollary to that demand has been an ever-growing need for more research into the phenomena associated with high speeds. While this need is particularly critical in aero-space research, it is also of keen interest in other scientific fields.

Traditionally, one of the most effective tools for observing high-speed phenomena has been the camera. But photography, too, has taken giant strides beyond the first crude system which revealed that a galloping horse takes all four feet off the ground at once. Today

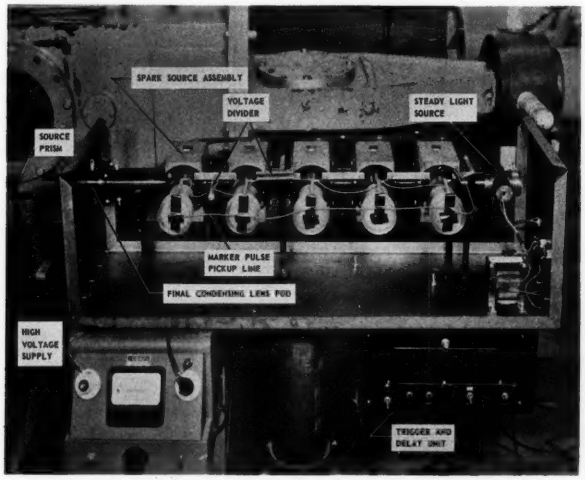


FIG. 1. **Multiple-spark light-source installation.**

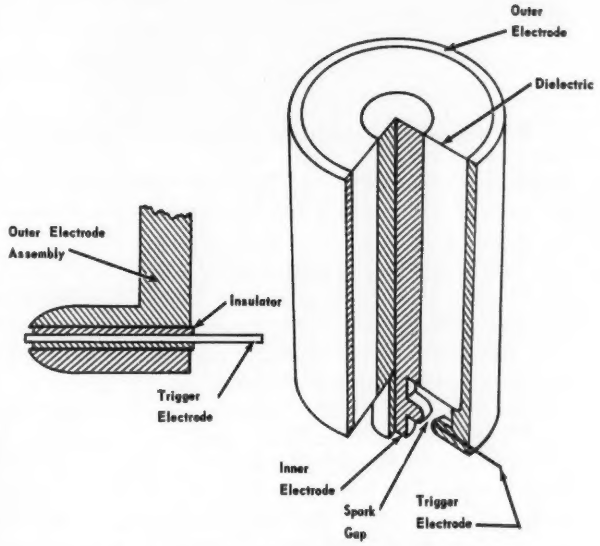


FIG. 2. **Cutaway of electrode assembly.**

these photographic advances can indeed provide the key to more effective, less expensive research.

Such an advance is the multiple-spark light source. Although this article relates the application of this photographic technique to hypersonic shock tunnels, it is a technique which can easily be used for direct photographs of such high-speed phenomena as ballistics; vibrations, e.g., flutter; or other bodies in motion within a confined space.

Research using hypersonic shock tunnels[1] poses the need for schlieren or shadowgraph pictures at several preset time intervals during a single test run which may last for as little as four milliseconds. Although a single-spark light system is used successfully in such photography, it unfortunately provides only a single picture of high-speed flow phenomena where several may be desired. A major disadvantage of this system is that many test runs must be made to obtain a complete photographic history of flow events — an expensive method at best.

A high-speed framing camera with a steady light source may be used to take high-speed movies. However, the image is usually small and the time resolution poor because of such long exposure times as 14 microseconds at 14,000 frames per second using 8 millimeter film. Furthermore, it is not always possible in many shock tunnels to use the framing camera because of the time required to bring the film to the proper speed.

Applications for Light Source

CAL's high-speed, multiple-spark light source is ideally suited for use with shock tubes, shock tunnels, and ballistic ranges. It is capable of producing flashes of high-intensity light of 0.1 microsecond duration for any preset time interval of more than 10 microseconds between sparks. It provides high-quality schlieren and shadowgraph photographs.

FIG. 3. **Light-source optical system.**

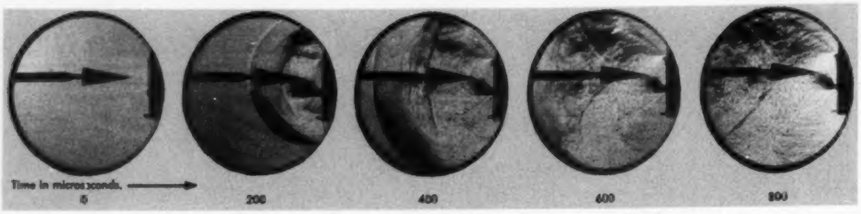


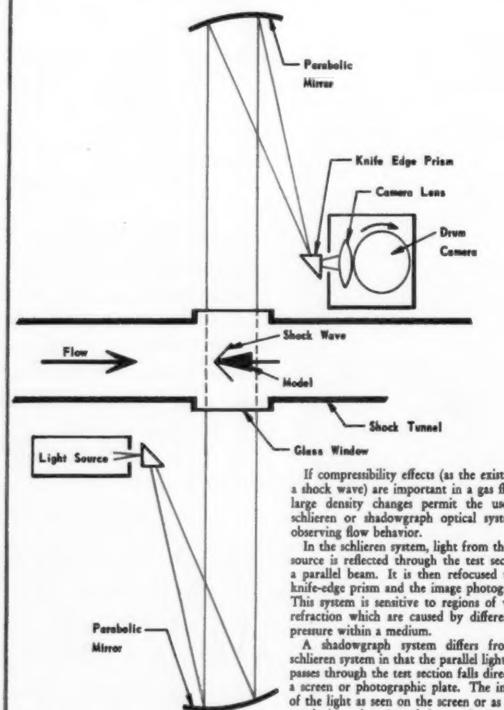
FIG. 4. **Schlieren photos of supersonic airstream over slender cone, taken with multiple-spark light source.**

There are numerous other high-speed photographic instruments available which can be used for the same assignment. Among these are the very high-speed shutter and the framing camera employing a rotating mirror.

For high-speed phenomena where a broad field of view is to be considered, such as a nuclear explosion, the light source described here would not be adequate because its primary purpose is to provide only a source of high-intensity light for use with a drum camera. For a study in which a source of light is already provided, an instrument incorporating a shutter and a moving film is required. In such applications, a high-speed framing camera of the Beckman and Whitely type is ideal.

Several systems incorporating a very high-speed shutter used with a high-intensity steady light source can be substituted for the multiple-spark light source. Among these systems the Kerr cell is well known. Nevertheless, in applications where test periods are prohibitively short and economy a primary consideration, the source described here is excellent for photographing high-speed phenomena.

What is a Schlieren System?



If compressibility effects (as the existence of a shock wave) are important in a gas flow the large density changes permit the use of a schlieren or shadowgraph optical system for observing flow behavior.

In the schlieren system, light from the spark source is reflected through the test section as a parallel beam. It is then refocused upon a knife-edge prism and the image photographed. This system is sensitive to regions of varying refraction which are caused by differences in pressure within a medium.

A shadowgraph system differs from the schlieren system in that the parallel light which passes through the test section falls directly on a screen or photographic plate. The intensity of the light as seen on the screen or as photographed is a function of the gas density.

The multiple-spark light source consists of five capacitors mounted in series and separated by lens assemblies (Fig. 1). Light is provided when the capacitors, set to discharge at different times, are triggered by a pressure pulse. This discharge across a spark gap aligned with the lens assembly focuses light on a right-angle prism which illuminates the subject, permitting the film on a drum camera to become exposed.

The spark-source assembly (Fig. 2) is so constructed as to allow adequate movement for lining up the gap in the center of the lens system. This design keeps the unit from turning and keeps the spark gap perpendicular to the lens system axis. Lens focus can be adjusted within the lens pods.

Five Spark Sources Used

Although CAL's system requires only five spark source assemblies, there is no mechanical limitation on the number of sources that can be used. There is, however, an optical limitation which will be discussed later.

A 10,000-volt source powers the spark system. Trigger pulses are provided at preset time-delays. A steady light source is used for initial focusing and sensitivity adjustment.

The spark source (similar in principle to one originally described by J. W. Beams et al[2]) takes advantage of a very short light flash produced by discharging a capacitor through a spark gap. In this light source, barium titanate capacitors[3] are charged to slightly less than the breakdown voltage of the spark gaps (8500 volts).

A small photo-flash trigger coil applies a pulse of several thousand volts to a trigger electrode concentrically located in a small hole drilled through the outside electrode to break down the gap to the inner electrode at the desired time.

Independently adjustable time-delays are provided for each spark. A delay of 100 to 2000 microseconds for the first spark allows flexibility of location for the trigger station. The remaining four delays, continuously variable from 50 to 500 microseconds each, cover the necessary range of camera drum speeds and testing times. Other ranges (e.g., 10-100, 500-5000 microseconds) can be made available. Consecutive triggering allows the time interval between individual flashes to be independently controlled.

A length of test lead wire placed near the center electrode of the barium-titanate capacitors forms a pickup that provides a marker pulse used to establish time correlation with other recorded data.

The possibility of producing more flashes or simplifying the present system by recharging the capacitor from a storage capacitor and recycling the timing system has been considered. The maximum firing rate of each gap appears to be limited by the de-ionization time of the air within the gap. Filling the gap enclosure with such a gas as argon or xenon or purging the area between the electrodes with a high-velocity air jet

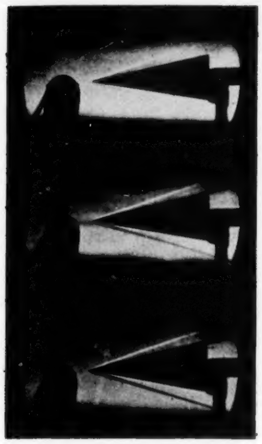


FIG. 5. **Shock wave over slender wedge taken with high-speed framing camera.**

might allow the recharging period of the flash capacitors to be reduced.

Optical System

Five individual spark lights are mounted in line with a lens system designed to focus the spark from the end electrode onto each preceding electrode, and finally on a common right-angled prism, where it is sent through the schlieren system. Each of the other four sparks is similarly focused on the preceding electrode so that all five come to focus at the same point on the common source prism. Thus, at preset time intervals, light can be furnished to the optical system from a common point. FIG. 3.

It is important that the spark gaps be aligned along the axis of the condensing lens system to eliminate distortion. A steady light source is needed to align the system with respect to lens and gap locations. This source is placed first at the spark assembly nearest the common source prism, where the first lens is focused in order to give a sharp image of the spark gap at the prism. Each successive spark assembly is put into place and its lens focused in like manner. At the same time the electrodes are positioned so that all sparks fall at the same point on the prism.

A noticeable decrease in light intensity occurs between successive sparks because of losses in the lens system. To compensate for this loss it has been necessary to decrease slightly the intensities of the brightest sparks by charging the capacitors from a voltage divider. All exposures then appear to be of the same light intensity. Because the spark intensity is extreme this was done with no ill effects on film exposure.

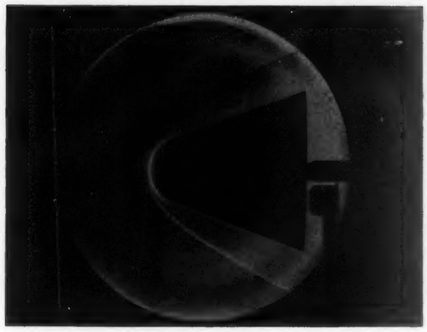


FIG. 6. **Single-spark schlieren photo of shock wave over blunt body.**

In preparing to record the light flashes from the spark source it is necessary to consider the image size as a function of drum camera speed and time delay between sparks. As the time delay is lengthened, a larger image can be used with the same drum speed without overlapping. Likewise, if the drum speed is increased, the time delay may be shortened while the image size remains constant or is increased.

System Uses Drum Camera

A 14-inch diameter drum camera[4] is used to record schlieren photographs with the multiple-spark light source. A 500-microsecond delay between sparks was used in typical tests, thus permitting a one-inch image when using a maximum drum speed of 2400 inches per second. *(Continued on page 8)*

ABOUT THE AUTHORS

DR. HERBERT A. NYE, author of *The Problem of Combat Surveillance*, has directed the Laboratory's Combat Surveillance Project for the U.S. Army Signal Corps in Washington since 1957.

Prior to being named Principal Physicist by the Laboratory in 1953, he served CAL as consultant while a member of the faculty of the University of Buffalo. In addition to his associate professorship there, Dr. Nye has been an instructor and an assistant professor at the University of Illinois.

At Cornell Aeronautical Laboratory, Dr. Nye's principal efforts have been in military systems analysis, in particular, studies examining the requirements for and the desirable characteristics of tactical air, missile and other weapon systems. In 1957 he became assistant head of the Systems Requirements department, the position he left to direct the Washington project.

Dr. Nye received his bachelor of arts degree in Physics from Allegheny College; his master of arts and doctor of philosophy degrees from the University of Illinois.

MERLE R. WILSON, coauthor of *Light Source for High-Speed Photography*, is young in years, but a veteran around shock tubes and tunnels. The author of several reports and papers on shock tunnel testing, Mr. Wilson has been occupied since joining the Laboratory in 1955 with experimental studies, research and design of hypersonic shock tubes and tunnels, and their instrumentation.

An Associate Mechanical Engineer at the Laboratory, Mr. Wilson is a graduate of Fenn College with a degree in mechanical engineering.

For RICHARD J. HIEMENZ, electronic instrumentation is an avocation as well as a vocation. His 15 years in electronics includes three years with the U.S. Army Signal Corps, six years with the Production Test Instrument Department of the Rudolph Wurlitzer Co., and two years as instructor for the American Radio Institute. Mr. Hiemenz joined Cornell Aeronautical Laboratory's Aerodynamic Research Department in 1955. Since then, much of his time has been devoted to instrumentation for shock tubes and tunnels.

RECENT CAL PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited; and those marked with an asterisk may be distributed only within the United States. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"STUDIES OF A PROTOTYPE WAVE SUPERHEATER FACILITY FOR HYPERSONIC RESEARCH," Smith, William E. and Weatherston, Roger C.; CAL Report No. HF-1056-A-1; December 1958; 115 pages.

The fundamental principles of wave superheater design and operation are developed. A prototype, designed to generate 3000°R in air and 5500°R in argon, starting from room temperature, has been built and tested. The unique flow conditions, characterized by homogeneity, purity, and high temperature, pressure, and velocity, that are generated in hypersonic shock tubes and shock tunnels for short periods can be sustained for many seconds.

"ACOUSTIC PROPAGATION IN A DIATOMIC GAS SUBJECT TO THERMAL OR CHEMICAL RELAXATION," Gibson, Walter E. and Moore, Franklin K.; CAL Report No. HF-1056-A-2; December 1958; 61 pages.

An acoustic equation is obtained herein for small disturbances from an equilibrium state of rest; this equation applies equally well to unsteady one-dimensional waves or to steady two-dimensional disturbances. The problem of two-dimensional airfoil in a supersonic flow of relaxing gas is also considered.

"RECENT ADVANCES IN TRANSIENT SURFACE TEMPERATURE THERMOMETRY," Hall, J. Gordon and Hertzberg, A.; Reprinted from Jet Propulsion, Vol. 28, No. 11; November 1958; 5 pages.

This paper reviews advances in transient surface temperature thermometry since 1953. A discussion of the thin and thick film techniques makes frequent reference to shock tube heat transfer application.

"ANALYSIS OF SOUTHERN CALIFORNIA FLIGHT TEST PROBLEMS," Blumstein, Alfred; CAL Report No. JA-1266-S-7; January 1959; 91 pages.

The background of the Southern California air traffic situation is discussed, along with pertinent accident history. Major problem areas are delineated and approaches suggested to the solution of collision problems in flight testing.

"FURTHER DEVELOPMENTS OF NEW METHODS IN HEAT FLOW ANALYSIS," Biot, M. A.; CAL Report No. SA-987-S-5; May 1958; 55 pages.

Lagrangian methods in heat flow problems and transport phenomena were introduced in a previous report. The present paper develops further one particular aspect of the method, i.e., the elimination of "ignorable coordinates."

"FACTORS AFFECTING AIRPORT CAPACITY AND THEIR APPLICABILITY TO SIMULATION," Smith, Milton D.; Tucholski, L.; and Dick, Ralph; CAL Report No. JA-1266-S-13; June 1959; 77 pages.

This is a report of an investigation of the air terminal final approach zone in order to provide a pre-simulation perspective of the parameters affecting terminal capacity. Aircraft and air traffic control system characteristics are examined.

(Continued from page 7)

Evaluation tests were made using a shock tube to accelerate air, initially at atmospheric pressure and temperature, to a speed of 1800 feet per second. These conditions were chosen, not because of any limitation of the light system when applied to higher velocity flows, but only to illustrate the usefulness of the instrument where photographs of a nonsteady flow system are desired. This unsteadiness would not have been as apparent to the untrained eye if photographs of a hypersonic air stream had been used.

Schlieren pictures were taken of the air flowing from the shock tube over a slender cone placed in the stream (Fig. 4). A delay time of 200 microseconds was used between sparks in order to photograph the flow field of particular interest in this test. Variations in the flow can easily be seen when the exposures are compared.

The spark source was triggered by a pressure transducer which was excited by the pressure behind the incident shock wave. An initial delay prevented the first spark from firing until the shock was visible at the end of the tube. Then the sequence of sparks was fixed at preset intervals and the results photographed with a rotating drum camera.

As mentioned above, the spark did not follow a straight line when jumping across the electrode gap, nor did it always follow the same path. It was thus necessary to place the projected spark gap perpendicular to the schlieren slit and knife edge on the source prism. Because the size of the enclosure did not permit the light source unit to be turned through 90°, it was necessary to use a right-angle prism for the source prism when a horizontal knife edge was used and a porro-abbe type prism (which rotates the image 90°) for a vertical knife edge. In this way the vertical traveling spark would always project itself upon a horizontal slit. Thus any amount of travel of the spark from a straight line across the electrodes would not decrease the amount of light provided to the schlieren system.

This procedure made available a source of light that was more nearly a point source, with the size of the source depending upon the slit height. The intensity of spark permitted a very small slit-height to be used without ill effect on film exposure, even when high sensitivity was required in the schlieren system.

During periods of high ambient humidity, system reliability was greatly reduced. A satisfactory solution was found by placing the unit in a fairly tight metal enclosure containing desiccant bags. The metal enclosure keeps the high voltage spark discharges from interfering with other sensitive instruments.

The flexibility and performance of the multiple-spark light source approaches and in some cases exceeds that of systems using expensive source-shutter combinations or high-speed cameras, and its general reliability recommends its use. Most parts are standard, but even special parts are relatively inexpensive.

REFERENCES

[1]*Research Trends*, Vol. VI, No. 1, Spring 1958 (copies available on request).

[2]Beams, Kuhlthau, Lapsley, McQueen, Snoddy, and Whitehead, J. Opt. Soc. Am., Vol. 37, p. 868 (1947).

[3]Fitzpatrick, Hubbard and Thaler, J. Applied Phys., Vol. 21, p. 1269 (1950).

[4]Type M 1020, Southern Instruments, Ltd., Camberley, Surrey, England.